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HEADQUARTERS
[illegible]TERMASTER RESEARCH & ENGINEERING COMMAND
U S ARMY

TECHNICAL REPORT
EP-71

THE PHYSIOLOGY OF LOAD-CARRYING XIV

[illegible] RESEARCH & ENGINEERING CENTER
[illegible] PROTECTION RESEARCH DIVISION

NATICK, MASSACHUSETTS

HEADQUARTERS
QUARTERMASTER RESEARCH & ENGINEERING COMMAND, US ARMY
OFFICE OF THE COMMANDING GENERAL
NATICK, MASSACHUSETTS

Major General Andrew T. McNamara
The Quartermaster General
Washington 25, D. C.

Dear General McNamara:

This report, "Evaluation of Army Combat Packs by Measuring Energy Costs and Speed of Movement," is a continuation of the load-carrying series. Since it requires energy to transport weight, and weight is distributed over the body in a different way with each load-carrying system, it is important for pack designers to know whether the work involved carrying a load is influenced by the design of the load-carrying system.

In this study, energy expenditures were determined for standard and experimental load-carrying systems. With the technique used, no outstanding differences were demonstrated for equal loads carried with the several load-carrying systems. Differences in the stability of the packs were observed, but these differences did not influence the energy cost of doing the tasks.

Sincerely yours,

C. G. Calloway

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EP-71

C. G. CALLOWAY
Brigadier General, USA
Commanding

HEADQUARTERS QUARTERMASTER RESEARCH & ENGINEERING COMMAND, US ARMY
Quartermaster Research & Engineering Center
Natick, Massachusetts

ENVIRONMENTAL PROTECTION RESEARCH DIVISION

Technical Report
EP-71

THE PHYSIOLOGY OF LOAD-CARRYING XIV

EVALUATION OF ARMY COMBAT PACKS BY MEASURING ENERGY COSTS AND SPEED OF MOVEMENT

Eng-Houw Tan, D.P.E.
Creighton J. Hale, Ph.D.
Peter V. Karpovich, M.D.

DEPARTMENT OF PHYSIOLOGY
SPRINGFIELD COLLEGE, SPRINGFIELD, MASSACHUSETTS

Project Reference:
7-83-01-005B

October 1957

Foreword

Objective methods that will clearly distinguish differences between similar types of load-carrying systems are difficult to develop. In this study, determination of the energy cost of "typical" military activities was assessed while the subjects carried the same load with different load-carrying systems. Conventional methods to determine energy expenditure were modified considerably to accomplish this. In addition to the data on the energy cost of the tasks, certain practical observations on equipment-induced interference with body movements were noted.

AUSTIN HENSCHEL, Ph.D.
Chief
Environmental Protection Research Division

Approved:

JAMES C. BRADFORD, Colonel, QMC
Commanding Officer
QM R and E Center Laboratories

A. STUART HUNTER, Ph.D.
Scientific Director
QM Research & Engineering Command

Contents

Abstract

The energy cost and speed of executing six performance tests were used as criteria for evaluating the U. S. Standard, U. S. Experimental, and British Experimental combat packs. A subjective rating based on comfort and freedom from interference with movements was also included for this evaluation. Tests of running, creeping, jumping, rolling, climbing, and falling-and-getting-up were performed without a pack and with each of the three different packs. Ten subjects were used.

Less energy was expended when activities were performed without a pack than with a pack. Nearly all tests were performed faster without a pack than with a pack.

On the basis of energy cost and performance time of each test, none of the packs can be considered definitely superior to the others.

According to the subjective rating, the U. S. Standard pack was the best, the U. S. Experimental pack second, and the British Experimental pack third.

EVALUATION OF ARMY COMBAT PACKS BY MEASURING ENERGY COSTS AND SPEED OF MOVEMENTS

1. Introduction

a. Most of the physiological studies related to pack carrying, whether in the laboratory or in the field, have been devoted primarily to marching or walking.[2,3,4,7,9,10] However, walking or marching, important as they may be, do not constitute the only type of locomotion used by the foot soldier during an actual combat situation. The soldier may need to creep, roll, climb, jump, run, and "hit the dirt". This he may do either slowly or at maximum speed. His survival may depend on his speed of movement.

b. Baily and McDermott[1] suggested that studies be conducted outside of the laboratory under conditions approaching those of combat. A similar need was pointed out by Renbourn.[8]

c. Experimental studies of various combat packs were reported by Hunter and Turl,[6] and by Hale and Karpovich.[5] The latter authors developed a battery of tests for the evaluation of the merits of different packs. These tests included: running, creeping, rolling, jumping, climbing, hand-grenade throwing, falling, getting up, changing direction, agility, and balance. Hand-grenade throwing was judged on accuracy, and jumping on distance. The Burpee test was used to measure agility, and a modified Bass Dynamic balance test was used for balance. The criterion for scoring the remaining tests was time of performance. No determination of the energy cost was made.

d. As far as the present investigators have been able to ascertain, no scientific studies have been made to determine the expenditure of energy while carrying a pack during the types of activities used by Hale and Karpovich.

For this reason 7 tests were taken from their study, and, after some modifications, combined into 6 tests. The falling ("hitting the dirt") and getting up from the ground, which were 2 separate tests, were combined into 1 test. In rolling, the number of turns was increased from 3 to 5. Descending the ladder was added to climbing. The standing broad jump was changed into 6 consecutive 5-foot jumps. Running, and creeping (II)* were retained unchanged.

e. The purpose of this study was to determine whether the energy cost and the time of performance of these selected tests with 3 different packs could be used as an objective basis for the evaluation of packs.

2. Materials and Methods

a. Materials

(1) Subjects. The test subjects were 10 male Springfield College students, 18 to 26 years of age, 64-3/4 to 76-1/4 inches in height,

*Hale and Karpovich had two tests of creeping, numbers I and II.

and 125½ to 210 pounds in weight (Table I). They wore the regulation U.S. Army wool combat uniform, with field jacket.

(2) Packs. The three types of combat packs used in this study were: (1) U.S. Standard pack,* (2) U.S. Experimental pack T53-8,* and (3) British Experimental pack UK-Z2. Each pack weighed 27 pounds; the manner in which each was carried is illustrated in Figures 1, 2, and 3.

(3) Location. All tests were conducted in the Springfield College Field House, which has a packed dirt floor.

b. Methods

(1) Types of locomotion. The types of locomotion included in this study were: (1) running, (2) jumping, (3) falling-and-getting-up, (4) creeping, (5) rolling, and (6) climbing.

(2) Description of tests.

Running (25 yards). Subject started from the standing position and sprinted with maximum speed for 25 yards. At the end of the 25-yard run a "pull up" of 15 yards was allowed. The time of the 25-yard run was recorded.

Falling-and-getting-up (4 times). Subject stood with the feet slightly apart (Figure 4a). He dropped to his knees, and at the same time slid his right hand to the heel of his rifle (Figure 4b). He then fell forward, breaking his fall with the butt of the rifle (Figure 4c). After landing on his elbow and forearm, he came into firing position (Figure 4d). Then he drew his arms inward, and with one movement raised the body by straightening his arms, and sprang to his feet, coming into the starting (standing) position (Figure 4a). The total time of four complete cycles of down-and-up movements was recorded.

Standing broad jump (6 consecutive 5-foot jumps). A distance of 30 feet was divided into 6 sections by parallel cross lines. Subject stood with his toes at the take-off line. He made a series of 6 consecutive 5-foot jumps forward (Figure 5). The total time of executing 6 jumps was recorded.

*The U. S. Standard pack referred to in this report was standard until 31 July 1957. The new standard pack is similar to the one referred to in this report as U. S. Experimental pack T53-8.

TABLE I: Age, Height, Weight, and Body Surface of Subjects

Subject	Age (years)	Height (inches)	Weight (pounds)	Body Surface (m^2)
J. A.	18	69-3/4	125½	1.67
B. B.	21	72	177	2.02
W. B.	19	71-3/4	210	2.19
R. B.	18	[illegible]	145	1.78
G. B.	26	70-3/4	142	1.82
L. C.	25	69¼	156	1.87
J. K.	21	66-3/4	165	1.86
C. P.	21	72½	179	2.04
P. T.	20	76½	189½	2.21
A. T.	24	64-3/4	165	1.81

a. Front **b. Rear**

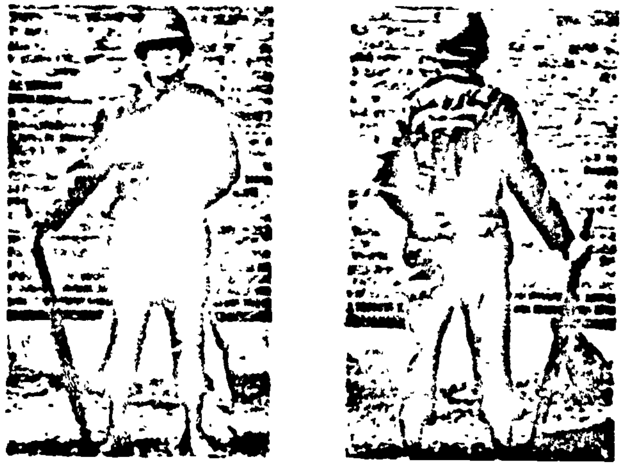


Figure 1. U.S. Standard Pack

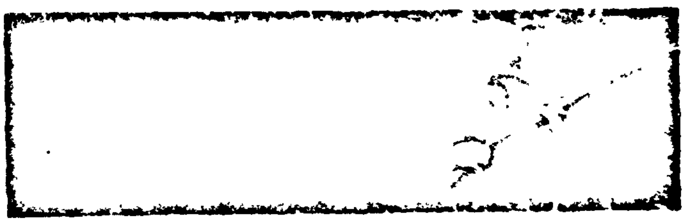
Figure 2. U.S. Experimental Pack T53-8

Figure 3. British Experimental Pack UK-Z2

a. Standing

b. Kneeling

c. Falling forward



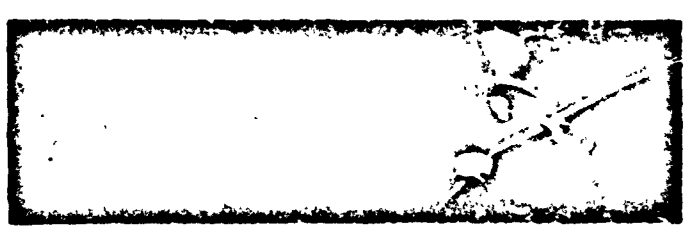
d. Prone

Figure 4. Falling and getting up

a. Standing

b. Kneeling

c. Falling forward



d. Prone

Figure 4. Falling and getting up

Figure 5. Standing Broad Jump

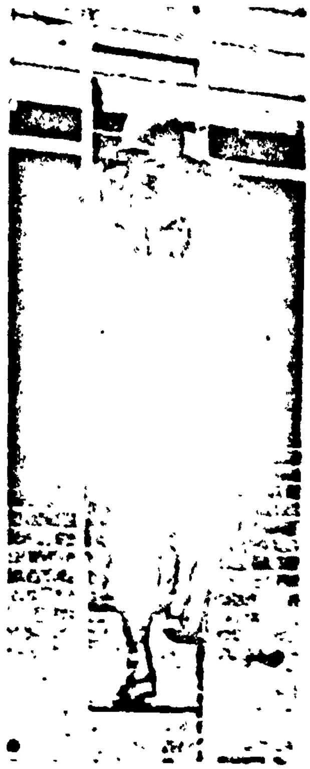


Figure 6. Climbing

Creeping (10 yards). Subject started from the prone position with the rifle cradled in the crooks of the elbows. He rested the weight of the body on his forearms, elbows, and lower legs, keeping the rest of the body off the ground. He moved forward by using his elbows and legs. The left elbow was advanced at the same time as the right knee. The time of creeping 10 yards was recorded.

Rolling sidewise (5 times). Subject lay in the prone position, with the rifle held with both hands under the body. Subject could choose to roll to the right or left. The total time of five rolls was recorded.

Climbing (12½ feet). Subject stood at the base of a vertical ladder. He climbed, stepping with each foot on alternate rungs of the ladder (Figure 6). Upon reaching the 12½ foot mark, he stood with both feet on this rung and then descended the ladder until both feet reached the ground. During the climb the subject grasped the

rungs with his hands. The distance between rungs was 1 foot; from the ground to the first rung it was 1.5 feet. The time of climbing, descending, and the total time were recorded. The rifle was not carried in this test.

(3) Testing procedure

Each test was administered 4 times: once without a pack and once with each of the 3 different packs. To control the effect of learning and training, the order of these tests was rotated. The subjects were requested to execute each test as rapidly as possible, and timing was done with stopwatches.

Prior to the testing, subjects were given instructions and test practice, and also were familiarized with breathing into Douglas bags. The subject rested for 30 minutes in a relaxed sitting position on a chair. At the conclusion of this period, the expired air was collected for 10 minutes in a 200-liter Douglas bag to determine the resting metabolism. After the Douglas bag was disconnected, the subject took the starting position for the test, and when the pack was used, it was placed on the subject's back by a tester. On the command "get set" the subject took a moderately deep breath. This breath was held throughout the test. Immediately after the test the subject sat again on a chair placed at the point where he finished the test. The expired air was collected in another Douglas bag during a 10-minute recovery period.

The air samples were collected in 50cc. syringes and were analyzed in duplicate with the Scholander gas analyzer for oxygen and carbon dioxide content.

The energy cost of the tests was expressed in net figures (gross oxygen used minus the resting oxygen consumption). It was also expressed as the ratio of cc. of oxygen used to the subject's body surface area.

(4) Subjective rating

The subjects were requested to rate the degree of discomfort and the amount of interference of each pack with the performance of the test. The range of rating was from one to three in order of increasing interference or discomfort.

3. Results

a. Energy expenditure

As could be expected, in each of the six tests the least amount of energy was used when tests were performed without a pack. This difference in the energy expenditure between the tests with a pack and the tests

without a pack was statistically significant (see Table II).

On the other hand, when the amounts of energy used in each test with each of the three packs were compared, no statistically significant difference was observed (see Table II).

b. Performance time

The expectation that performance time without a pack would be less than with a pack was true except in the following:

(1) Falling-and-getting-up was performed as rapidly while carrying the U. S. Experimental pack or the British Experimental pack as when no pack was carried.

(2) Climbing was performed as rapidly while carrying the British Experimental pack as when no pack was carried. There was, however, a trend ($t=1.73$) toward a faster performance without the pack.

(3) Descending was performed as rapidly with any of the three packs as without a pack.

(4) Climbing and descending as a unit was performed as rapidly with any of the three packs as without a pack.

There was no statistically significant difference between the times for each test with each of the three packs as shown in Table III.

c. Subjective rating of packs

According to subjective rating of packs, based on comfort and interference of movements, the U. S. Standard pack was rated the best and the U. S. Experimental pack rated a close second.

The U. S. Standard pack was preferred to the other two packs in creeping, falling-and-getting-up, and climbing; while in running it received the same rating as the U. S. Experimental pack. For such activities as rolling and jumping, the U. S. Experimental pack was rated the best.

4. Discussion

a. The number of subjects in this study was limited to ten. Although for statistical analysis a larger number of subjects would be desirable, a larger series was not practicable.

b. There was no statistically significant difference between the three packs when the energy consumption or the time required for tests was compared. This observation may be interpreted as an indication that

TABLE II: COMPARISON OF ENERGY COST OF TESTS WITHOUT A PACK AND WITH THREE DIFFERENT PACKS (cc. of oxygen per sq. meter of body surface)

		No Pack	US Stan	US Exp	Brit Exp	No Pack	US Stan	US Exp	Brit Exp
		RUNNING				**JUMPING**			
No Pack	D		-199	-165	-211		-209	-216	-207
	t		2.62*	1.88*	2.54*		2.71*	2.88#	2.80*
US Stan	D			34	-12			-7	2
	t			.45	.55			.08	.02
US Exp	D				-46				9
	t				.55				.11
Means		841	1040	1006	1052	512	721	728	719
SEM		62	44	62	55	47	61	59	58
SD		186	131	185	166	141	183	177	175
		FALLING-and-GETTING-UP				**CREEPING**			
No Pack	D		-225	-198	-242		-329	-359	-379
	t		2.59*	2.30*	2.88#		3.39#	3.45#	3.71#
US Stan	D			27	-17			-30	-50
	t			.42	.21			.28	.47
US Exp					-44				-20
					.54				.18
Means		901	1126	1099	1143	1063	1392	1422	1442
SEM		63	58	60	55	65	72	82	78
SD		188	173	181	166	196	216	247	233

D: Difference between means in cc.
t: t-ratio

* Statistically significant at .05 level of confidence (minimum t-ratio at this level is 1.83).

\# Statistically significant at .01 level of confidence (minimum t-ratio at this level is 2.82).

A positive difference indicates that the energy cost for an item listed on the left is greater than the energy cost for an item listed at the top.

TABLE II (cont.)

		No Pack	US Stan	US Exp	Brit Exp	No Pack	US Stan	US Exp	Brit Exp
		ROLLING				CLIMBING			
No Pack	D		-180	-188	-179		-228	-246	-310
	t		2.14*	2.97#	2.59*		4.56#	3.57#	4.49#
US Stan	D			-8	1			-18	-82
	t			.12	.01			.27	1.24
US Exp	D				9				-64
	t				.11				.85
Means		550	730	738	729	699	927	945	1009
SEM		54	43	54	64	30	40	53	53
SD		162	129	163	191	89	120	160	160

D: Difference between means in cc.
t: t-ratio

* Statistically significant at .05 level of confidence (minimum t-ratio at this level is 1.83)

\# Statistically significant at .01 level of confidence (minimum t-ratio at this level is 2.82)

A positive difference indicates that the energy cost for an item listed on the left is greater than the energy cost for an item listed at the top.

NOTE: The conventional t analysis (paired comparison) was used in this investigation. Although this was the classical technique where more than two groups were compared, multiple comparison tests now available, such as analysis of variance, would be more appropriate. Once an overall difference is established on the basis of analysis of variance, comparisons between groups are justified. In this connection, newer non-parametric techniques are available.

TABLE III: COMPARISON OF PERFORMANCE SCORES WITHOUT A PACK AND WITH THREE DIFFERENT PACKS (Score in seconds)

		No Pack	US Stan	US Exp	Brit Exp	No Pack	US Stan	US Exp	Brit Exp
		RUNNING				**JUMPING**			
No Pack	D		-.47	-.42	-.54		-.70	-.74	-.79
	t		4.48#	3.50#	4.50#		2.41*	3.52#	3.95#
US Stan	D			.05	-.07			-.04	-.09
	t			.38	.54			.13	.29
US Exp	D				-.12				-.05
	t				.86				.21
Means		4.28	4.75	4.70	4.82	3.79	4.49	4.53	4.58
SEM		.07	.08	.10	.10	.12	.27	.18	.16
SD		.22	.24	.29	.29	.35	.80	.54	.49
		FALLING-and-GETTING-UP				**CREEPING**			
No Pack	D		-1.19	-.68	-.71		-2.22	-2.05	-1.73
	t		2.[illegible]*	1.05	1.18		3.70#	3.66#	2.11
US Stan	D			.51	.48			.17	.49
	t			.72	.76			.13	.32
US Exp	D				-.03				.32
	t				.05				.23
Means		13.92	15.11	14.60	14.63	10.62	12.84	12.67	12.35
SEM		.51	.40	.51	.49	.69	1.05	.83	1.11
SD		1.54	1.20	1.53	1.48	2.08	3.16	2.48	3.32

D: Difference between means in seconds
t: t-ratio

* Statistically significant at .05 level of confidence (minimum t-ratio at this level is 1.83).

\# Statistically significant at .01 level of confidence (minimum t-ratio at this level is 2.82).

A positive difference indicates that the performance score for an item listed on the left is greater than the performance score for an item listed at the top.

TABLE III (cont.)

		No Pack	US Stan	US Exp	Brit Exp	No Pack	US Stan	US Exp	Brit Exp
		ROLLING				CLIMBING-and-DESCENDING			
No Pack	D		-1.13	-1.05	-1.01		-.47	-.62	-.81
	t		2.83#	2.02*	2.24*		.63	.73	.90
US Stan	D			.08	.12			-.15	-.34
	t			.14	.21			.20	.43
US Exp	D				.04				-.19
	t				.07				.21
Means		5.47	6.60	6.52	6.48	9.98	10.45	10.60	10.79
SEM		.41	.41	.41	.38	.61	.45	.60	.66
SD		1.24	1.22	1.22	1.14	1.82	1.35	1.80	1.97

		No Pack	US Stan	US Exp	Brit Exp	No Pack	US Stan	US Exp	Brit Exp
		CLIMBING				DESCENDING			
No Pack	D		-.52	-.50	-.52		.04	-.12	-.28
	t		2.60*	2.00*	1.73		.08	.24	.57
US Stan	D			.02	0			-.16	-.32
	t			.05	0			.33	.65
US Exp	D				-.02				-.16
	t				.04				.33
Means		4.47	4.99	4.97	4.99	5.51	5.47	5.63	5.79
SEM		.29	.20	.31	.33	.34	.34	.34	.35
SD		.88	.59	.94	.99	1.02	1.02	1.02	1.05

D: Difference between means in seconds
t: t-ratio

\# Statistically significant at .01 level of confidence (minimum t-ratio at this level is 2.82).

* Statistically significant at .05 level of confidence (minimum t-ratio at this level is 1.83).

A positive difference indicates that the performance score for an item listed on the left is greater than the performance score for an item listed at the top.

from the standpoint of mechanics the three packs are much alike. The principal differences between these packs are: (1) the U. S. Experimental pack and the British Experimental pack have two ammunition pouches attached to the front of the belt, whereas the U. S. Standard pack has not, and (2) the distribution of the 6- to 8-pound load carried on the back is not the same for each pack. These differences in design, however, did not cause detectable differences in metabolism or time of performance.

c. Although the British Experimental pack received the lowest subjective rating, the men could perform the tests with this pack as fast as with the other two packs.

d. Subjects complained of discomfort and interference caused by the two ammunition pouches of the U. S. Experimental pack and the British Experimental pack. For this reason one might expect a greater oxygen consumption and slower movements with these packs than with the U. S. Standard pack. Yet this did not happen. Possibly the tests used were of too short duration. One may speculate whether longer tests might not detect some effect of the pouches upon performance.

e. It was observed that when the load was carried high on the back, as were the U. S. Standard pack and the British Experimental pack, the load bounced up and down and sidewise during all tests except creeping and climbing. This bouncing was particularly violent when the subjects were "hitting the dirt." During this activity the load on the back and the intrenching tool bounced against the neck and head, frequently displacing the helmet.

5. Summary

a. The U. S. Standard, U. S. Experimental, and British Experimental combat packs were compared, using energy cost and time required for executing six performance tests. Ten men were used as subjects, and tests were done with and without the pack.

b. The performance tests included running, jumping, falling-and-getting-up, creeping, rolling, and climbing.

c. In each test the energy expenditure was lower when no pack was carried. When the amounts of energy used in each test with each of the three packs were compared, no statistically significant difference was found.

d. Tests were performed faster without a pack than with any of the packs except

(1) falling-and-getting-up was performed as rapidly while carrying the British Experimental pack or the U. S. Experimental pack as when no pack was carried,

(2) Climbing was performed as rapidly while carrying the British Experimental pack as when no pack was carried,

(3) Descending was performed as rapidly with any of the three packs as without a pack, and

(4) Climbing and descending as a unit was performed as rapidly with any of the three packs as without a pack.

e. Subjective evaluation showed that the U. S. Standard pack was preferred, with the U. S. Experimental pack a close second.

6. Conclusions

a. On the basis of energy cost and performance time of each test, none of the packs can be considered definitely superior to the others.

b. According to the subjective rating, the U. S. Standard pack was the best, the U. S. Experimental pack second, and the British Experimental pack third.

7. Recommendations

a. That the study of performance tests in pack evaluation be continued.

b. That the number of subjects for such a study be increased and the tests made of longer duration.

8. Acknowledgments

The assistance of Mrs. L. M. Ewing, Miss D. Ring, and Messrs. O. D. Grebenschikoff and L. Candido of Springfield College is gratefully acknowledged.

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